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Coding message criticality level on a data link display

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CODING MESSAGE CRITICALITY LEVEL ON A DATA LINK DISPLAY

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ABSTRACT

CODING MESSAGE CRITICALITY ON A DATA LINK DISPLAY

By Joanne Marie Chang Lins

This study investigated the potential to code message criticality into a pilot's data link display while taxiing with an electronic moving map (EMM). Five coding conditions were tested: plain text, expedite text, expedite color, expedite icon, and expedite reverse video. New text messages, including Contact Tower, Cleared to Cross, Stop, Change Route, and Slow Down, appeared as pilots taxied toward a designated runway. Eye tracking, magnitude of response, and mean taxi speed data was collected to measure pilots' reactions to the events. Subjective participant preference data was also collected via a post-experiment survey. The results from this study, whilst not significant, do suggest a beneficial trend for using some form of salience coding (color, icon and reverse video) for conveying urgency in a data link message. This study confirmed that there is a need for urgency level to be coded into data link messages.

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More Digital Communication than Written

The invention of the personal computer has profoundly changed the way that humans communicate both socially and at work. Angiollo (1999) suggests that e-mail has surpassed voice calls, letters, and faxes as the main form of communication for millions of Americans. In fact, 30 million Americans regularly use e-mail (Angiolillo, 1999). Prior to e-mail, most business communication was done face-to-face, by memo, or by telephone. Many studies have been carried out to determine how the medium of communication changes and shapes what is communicated.

How Electronic Mail Differs From Other Forms of Communication

Have you ever received a letter or spoken to someone on the telephone and had a nagging feeling that you were missing something that they were trying to communicate and felt sure that you would have understood it if only they had been there in person?

This scenario illustrates that there are many differences in communication between face-to-face communication, writing, and talking on the telephone. The obvious difference is in the number and type of channels through which you receive information; in face-to-face communication information can be gathered from vision, hearing, and sometimes touch. When speaking on a telephone you are limited to hearing and when communicating via letter you are limited to sight.

When talking face-to-face, information is communicated in the words that are spoken as well as through the intonation of those words (Smith, 1991). Other non-verbal information is communicated through eye contact and gaze, personal space, gestures and body language, feedback channels (e.g., the other person shaking their head in agreement or giving a confirming "mmmm"), interruption, and turn taking (Dix, Finlay, Aboud and Beale, 1998).

When communicating on a telephone, visual cues are absent but cues are still provided through feedback channels, interruption, and turn taking. These cues provide information that can shorten a conversation, as each party can quickly determine if they agree, disagree, are talking about different things, or are talking on different levels. To further illustrate this point, Kaiser and Wehrle (1999) provide the example of a teacher explaining a theory to a student. If the student frowns and shakes their head, the teacher will automatically start to explain the theory in simpler terms. If this scenario is applied to a telephone conversation between the teacher and the student, the student may verbally indicate puzzlement, e.g., by saying "umm," and this will let the teacher know that the student does not understand. If this scenario is extended still further to that of a teacher and a student conversing though e-mail, the teacher may spend considerably more time explaining the theory at a level that is beyond the student's comprehension as the teacher does not get the immediate "I'm puzzled" feedback, and so will not realize that the student is not understanding their explanation.

E-mail communication is limited to the content of the words and any additional information provided by punctuation, type, and page layout (Smith, 1991). Dix et al. (1998) suggest that as any method of communication develops, a culture for its use and rules develop with it. With such an increase in the use of electronic mail in recent years, efforts have been made to convey more of the non-verbal cues that are present in other forms of communication as discussed below.

Guidelines Have Been Developed for Effective E-mail Communication

Some current research is investigating the use of non-verbal communication in human-computer interaction, for example, Kaiser and Wehrle (1999) investigated ways to incorporate facial expression into non-verbal human computer interaction; however, the practical application of these techniques is still a long way off.

Emoticons and acronyms are used in e-mail communications to help convey information faster than typing text. Emoticons are formed from simple ASCII characters and represent simple "faces" presented sideways. These can improve the speed of communication and help avoid misunderstandings, provided that that the other person also knows their meaning. Examples of some of the most commonly used emoticons and acronyms and their meanings are presented in Table 1.

Table 1

Examples of Common Emoticons and Acronyms and Their Meanings

Emoticon/Acronym	**Meaning**
:-)	Happy, a joke
;-)	Winking, sarcasm
:-(	Unhappy
:-O	Surprise
ROTFL	"Rolling on the floor laughing"
AFAIK	"As far as I know"
IMHO	"In my humble opinion"

Consider the following two sentences:

Don't you just love the suit that John was wearing? ;-)

And

Don't you just love the suit that John was wearing?

When reading the above sentences the "winking face" emoticon conveys the meaning that the writer did not really like the suit while the opposite meaning could be taken from the second sentence. If the first sentence was said in conversation, the sarcastic meaning would be clear from the use of tone and facial expression. Methods have also been developed to convey other types of information such as urgency. In some e-mail reader applications, e.g., Microsoft's Outlook Express, the urgency of an entire message is conveyed through the use of a red exclamation mark at the beginning of the message line (as shown in Figure 1).

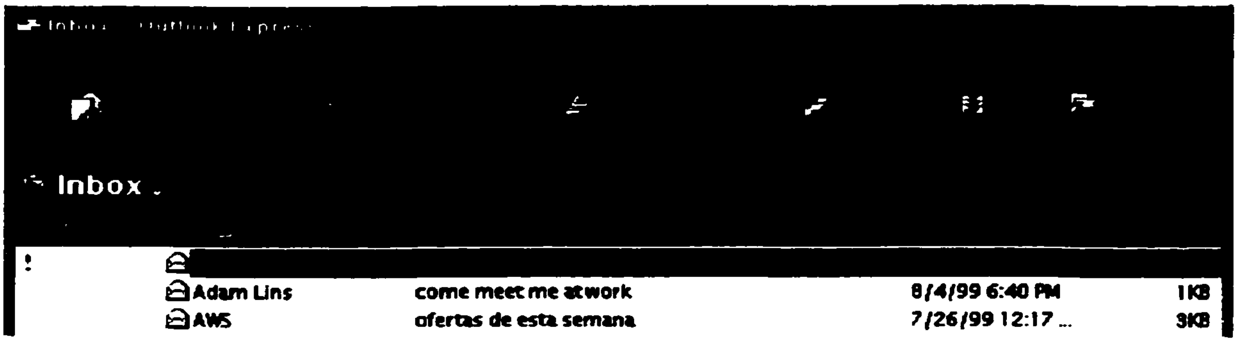

Figure 1. An Urgent Email Message. The red exclamation mark indicates that the message is urgent.

The exclamation mark conveys that the message is urgent but does not help to convey the meaning of the message.

In situations where messages need to be conveyed urgently in a digital format there are no auditory cues such as the loudness or speed of the voice, so other methods of displaying urgency may need to be developed. The question is: how can a message best be coded to communicate that it must be responded to urgently? Such a situation occurs in a new proposal called *data link* through which air traffic controllers and pilots will communicate via short text messages. It should be noted here that whilst data link shares some of the characteristics of e-mail, it has some differences. These differences include: data link messages will be context dependent, have a more structured format, may require a response in a timely fashion and will generally have a lower tolerance for misunderstanding. The lower tolerance for misunderstanding could become critical if for example a pilot crosses a runway that is in use. It is therefore critical that attention be paid to optimizing data link message structure and format so that messages can be responded to in an accurate and timely manner.

Data Link in Aviation: Different Domain, Same Issue

The current communication system. An important first step in defining the problems that may occur in the proposed data link system is to determine in what ways the current and proposed systems differ from each other. Historically, communication between the air traffic controller and the pilot has been by way of radio-telephone. The types of message conveyed between the two include air traffic clearances and flight advisory and warning information (Kerns, 1999). The information is broadcast over a VHF channel, providing the same information to a number of pilots simultaneously in a manner similar to a telephone party line. This shared information is useful, e.g., by allowing a pilot to know that another plane ahead is experiencing turbulence. It has also served to provide fault-finding information, e.g., when an air traffic controller gives two planes clearance for the same runway at the same time.

The existing speech-based communication method consists of a limited vocabulary of standard phraseology. For example, if under the current verbal system the air traffic controller (ATC) requires that a pilot drop 2000 feet they will say "drop 2000 feet." However, if it is urgent that the pilot drops 2000 feet in order to avoid imminent danger, the air traffic controller will say "expedite drop 200 feet now." The inclusion of "expedite," the voice intonation, and the speed of the speech of the air traffic controller conveys the urgency of the situation.

The Federal Aviation Administration (FAA) is currently pursuing a change from the radio-telephone communications system to the data link system whereby some of the information previously communicated by voice will now be communicated through a text-based interface. Darby and Shingledecker (1998) report that the FAA expects to be "data link compliant in the National Airspace System (NAS) by 2003." Thus data link is a new domain involving electronic communication where verbal communication has prevailed.

Benefits of data link. The main benefit of data link is that it will reduce VHF bandwidth congestion (Navarro & Sikorski, 1999). In addition to this it is expected that data link will eliminate problems caused by phonetic similarities, ambiguity, and overlapping transmissions (Kerns, 1991), and that data link will give both pilots and ATC greater flexibility in managing their workload as the communication does not require both parties attention at the same time (Konicke, 1990). To give an idea of the extent of the problems currently being experienced with the voice system, Cardosi, Boole, and Volpe, (1991) examined transcripts of en route flight ATC to pilot communications. Their findings suggest that the most important communication period is when an immediate maneuver is required for traffic avoidance. The study found that 14% of calls during critical periods required the controller to repeat or clarify part or the entire message. It is important to note that while there are expected to be many benefits of data link, this new communication medium will result in some differences in the information exchanged in each transaction. A number of studies have been conducted to determine in what ways the communication exchange is changed when using a data link communication system.

Previous Data link Studies

A number of studies have been conducted to determine the impact that the new electronic text-based system will have on flight compared to the existing speech-based system. A complete review of the findings from simulation studies can be found in Kerns (1999). Kerns reports that studies have been conducted in the following areas: "*Communications efficiency, speed and timing of communications, workload, implications of party-line information, design-dependent effects – operational communications, flight crew and controller procedures, user-system interaction, automation, display surfaces and location, display modes and formats.*" Our interest in this thesis is how to alert the pilot to the level of criticality of a message.

Data link Usage

A number of studies suggest that current representations of data link will be acceptable to pilots during oceanic phases but not in terminal airspace where messages can be more time critical (van Gent, 1995). In terminal airspace, pilots would still prefer to use voice radio-telephones. Konicke (1990) proposes the following message classification system for determining which messages should be sent by data link and which should be voice. Konicke (1990) splits messages into three types. The first level (termed Communication 1) requires immediate action. The second level, called Communication 2, requires prompt action and the third level, Communication 3, requires a timely response. While these levels are not clear cut they do provide a framework from which it is clear that in the new data link system some means of distinguishing between urgency levels conveyed with each message is needed.

Konicke (1990) suggests that Communication 1 messages should continue to be transmitted by voice and that Communication 2 and 3 could be transmitted via data link. The question then presented is how to distinguish between Communication 2 and Communication 3 messages with data link. In the current voice medium, such a distinction is implied through the air traffic controller's voice (Navvaro and Sikorsky, 1999).

Displaying Time Critical Information

When conveying time critical messages, three levels of alert can be identified. The first level informs that a message has arrived and can indicate that the recipient should view the message urgently or not urgently. Level two alerting relates to presenting the information in such a way as to have the shortest possible processing time, maximizing the speed of the required subsequent action. The third level is how to code the level of criticality of the message on the data link screen; this can be achieved through the manipulation of color, layout and symbology used. Our interest in this thesis lies in the third level, coding the criticality of the message. Previous research into the three levels of alerting is discussed in greater detail below.

Level 1: Message Exists. A number of studies have been conducted into how best to alert the crew that a message has arrived (van Gent, 1995; Rehmann, 1996). In a simulator study, Rehmann (1996) found no significant differences in response time when comparing a non-distinctive SELCALL alarm to a non-distinctive SELCALL-Plus and annunciator lamp. Van Gent, (1995) investigated the alerting properties of four different designs: a SELCALL chime used for all messages, a SELCALL chime used only for critical messages, two different tones used to indicate message criticality, and a sonar ping for critical messages only. The results from this study also found no difference in reaction times from the proposed designs. Rehmann (1995) identified nine different issues that need to be considered for data link alerting, including:

- volume of the alert (alerts can be too loud or too low),
- the need for aural backups for visual alerts, the lack of standardization for alerts,
- the need for prioritization and inhibit logic for multiple alert activation,
- distinction between alerts, procedures for responding to an alert,
- external factors such as sunlight and low light

For further information about these issues see Rehmann (1995). It is important to note that some of these alerting problems were found in the van Gent (1995) study. The study reported that when the SELLCAL alert was used, seven out of ten times the crew incorrectly checked for an ATC message compared with only one out of eleven times under the distinctive alert sound.

Level 2: Urgency of Action. In terms of optimal display format, a number of studies have compared graphical, alphanumeric, and mixed displays on aircraft interfaces (LaLumiere-Grubbs et al., 1987; Camacho, Steiner & Berson, 1990; Hahn & Hansman, 1992). These studies suggest that icons can produce faster response times than alphanumeric (Camacho, Steiner & Berson, 1990), symbolic displays can produce faster and more accurate reaction times than text (LaLumiere-Grubbs et al., 1987), and that graphical representation of spatial information can produce faster response times and provide more error detection in ATC messages than textual or verbal representation (Hahn & Hansman, 1992).

Level 3: Urgency of Action. This level relates to how the criticality of the message can be conveyed on the display. An example of this can be seen in the dialogue boxes that appear under Microsoft Windows 9x applications, an example of which is shown in Figure 2.

Figure 2. Warning Dialogue Box.

This dialog box appears if the user attempts to open a new file when working in a file that has not yet been saved. Criticality is suggested by the exclamation mark in the yellow triangle. In addition to the appearance of the dialogue box, the only further action that can be taken by the user is to click on one of the three command buttons. The earlier example of the red exclamation mark at the beginning of a message line in Outlook Express can also be seen as an indication of criticality. In aviation data link displays, Groce and Boucek (1987) indicated levels of criticality by using reverse video for urgent messages, green for normal messages, and flashing text to indicate the part of the display that required attention. For example, the text "ATC uplinks pending" would flash when an uplink was pending. In a similar fashion, Hinton and Lohr (1988) used reverse video to indicate new messages. In research for this thesis, no study could be found that compared various display format techniques on their perceived degree of criticality.

This study will further investigate the question of how criticality can be conveyed on the data link display screen (level 3 alerting).

Potential to Code Urgency

In developing a display from which the criticality of the message can be quickly ascertained, it is important to use techniques that direct the user's attention and facilitate fast comprehension. To achieve this, attention must first be drawn to the part of the display screen that holds the critical information and then the information must be coded to facilitate fast processing. With regard to directing attention and facilitating information processing two important points should be made:

1. The overriding mechanism through which attention is drawn to any particular part of the screen is through user expectation (Wickens, 1992). The implication of this for the display design is that while other attention getting factors can be manipulated they will not achieve optimal success unless their placement and form is consistent with the user's expectations.
2. Once the above expectation criteria have been met, some methods that aid attention getting hinder information processing. For example, while blinking attracts attention the information can only be processed when the information is visible.

In this study the Boeing 737 data link chime will indicate new messages. Messages will always be preceded by this chime and will be displayed in a consistent location. Visual techniques considered for this study that both attract attention and facilitate information processing include: use of different language, text size, capitalization, bolding, color, icons, pictorial representations, reverse video, and parsing of information. Three of these techniques used in three different displays have been selected for this study: color, reverse video, and icons. A plain text and a text display containing the word expedite were also designed to provide baselines for comparison. Justifications for each of the selected techniques are set out below:

Color. Previous research indicates that color can be used to highlight information within cluttered displays, facilitating faster target search times (Tan & Fisher, 1987; Fisher & Tan, 1989; Tse, 2001). Philipsen (1994) also suggests that color can aid in processing efficiency. The use of color highlighting directs user attention to the highlighted part of the display, which creates the effect that the highlighted information "pops out" of the display (Marten & Wickens, 1995).

Jubis (1990) suggests that the use of redundant color coding in a display can improve search performance due to the parallel processing capability of color. Previous research suggests that information is processed by the central nervous system in the following order: color, shape, and then alphanumeric information (Berry, 1967). Berry (1967) suggests that this may allow color-coded information to be processed earlier in time.

A number of aviation studies have incorporated color-coding into their displays. For example, Wickens, Miller and Tham (1996) investigated the effect of displaying 2D and 3D information on data link displays, using displays depicting aircraft blinking red if a descent was involved, blue if a climb was involved, and purple if the aircraft was turning only. Note, however, that as Wickens et al. did not specifically manipulate color it is unclear if there was any benefit due to this coding scheme. Degani (1992) suggests that in aviation red is associated with danger, green with normal and amber with caution.

For this study a red text display was chosen as this color conforms to the population stereotype that red suggests danger or represents a warning. Examples of red being used to convey such messages can be seen in traffic lights and traffic signs. An example of a color coded message can be seen in Figure 3.

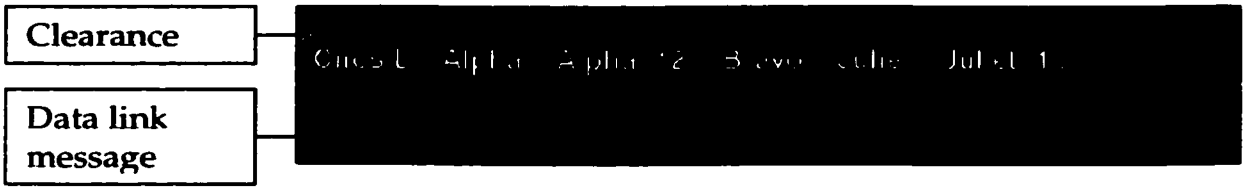

Figure 3. Color Message.

Reverse video. A second solution, reverse video, is a variation on the use of color, and so has the same potential benefit of being processed early. Some studies have noted a poorer search performance when participants have been asked to find selected information displayed in reverse video than when displayed in color (Philipsen, 1994; Fisher & Tan, 1989). However, reverse video is often used in aviation displays. As was mentioned previously, both Hinton and Lohr (1988) and Groce and Boucek (1987) used reverse video for urgent messages, allowing the user to look for a color pattern on the display to determine message urgency. An example of this format can be seen in Figure 4.

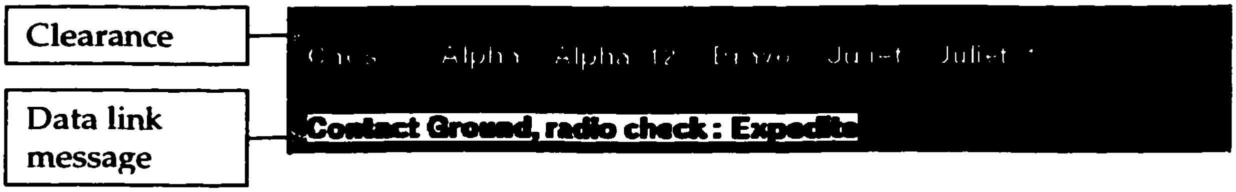

Figure 4. Reverse Video Message.

Icons. Icons and pictorial representations are encountered with increasing frequency in daily life with two notable examples being computer icons and traffic signs. Icons have the advantage that they are often language independent and so can be interpreted equally well by people who speak different languages. A second advantage is that icon meanings become a well-practiced stereotype because the same representations are used in different settings.

Research on the relative benefits of icons being used instead of text has not been conclusive. The benefits of icons over words to communicate information have been studied in the aviation setting by Camacho et al. (1990); Selcon, Taylor & Shadrake (1992); and Lalumiere-Grubbs et al. (1987). Lalumiere-Grubbs et al. (1987) investigated the effect of format type, complexity, and symbology in a simulated task involving pilots monitoring one display and reacting to another. The study found faster reaction to symbolic formats than to symbolic and text displays or text only displays. Camacho et al. (1990) also found that participants could both find and react faster to icons than to alphanumeric messages.

Wogalter, Jarrard, and Simpson (1994) investigated the perceived effect of different ways of conveying warning information on consumer household products and found no significant change in hazard rating level when an icon (an exclamation point surrounded by a triangle) was added to a warning message. This study did find an increased hazard rating if the one of the following words were added: note, warning, danger, or lethal.

Two important factors in the success of an icon to convey information are how representative the icon is of the information it is intended to convey and how easy the icon is to interpret (Familant and Detweiler, 1993). Familant and Detweiler (1993) suggest that problems in interpretation can occur when the look of the icon is not strongly coupled to a conceptual model. To illustrate this point, Familant and Detweiler (1993) provide the example of the Xerox Star computer that used icons developed from the physical objects that they represented, such as folders. This suggests that it may be difficult to develop icons that represent meanings that can not be well represented physically such as the need to convey that a response is required urgently.

The icon chosen for this experiment was a triangle with an exclamation mark inside it. This icon was chosen as it has the clear triangular global shape often used in traffic signs to communicate caution. Global shape is important as this is the first concept that the user will recognize and in degraded light situations it may be the only part of the icon that can be made out (Wickens, 1992). The exclamation mark was chosen as it is often used in computer programs to indicate warnings and is being used to indicate urgent email messages in some computer applications, so we are expecting to leverage some degree of familiarity. See Figure 5 for an example of this data link message.

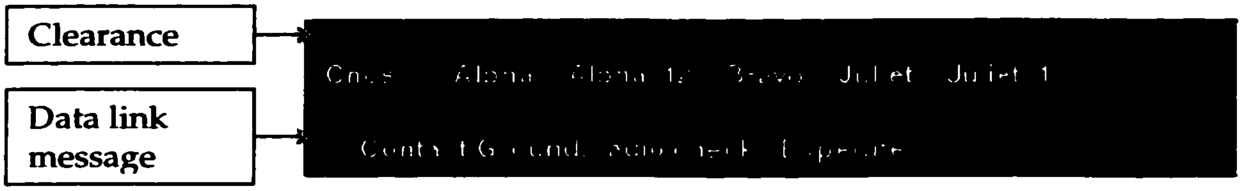

Figure 5. Icon Message.

Plain Text. A plain text and an expedite text display were used to provide a baseline to test the other designs against. The plain text example can be seen in Figure 6 and the expedite text example can be seen in Figure 7.

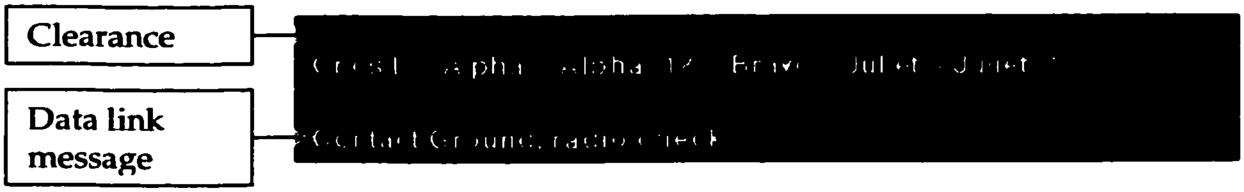

Figure 6. Plain Text Message.

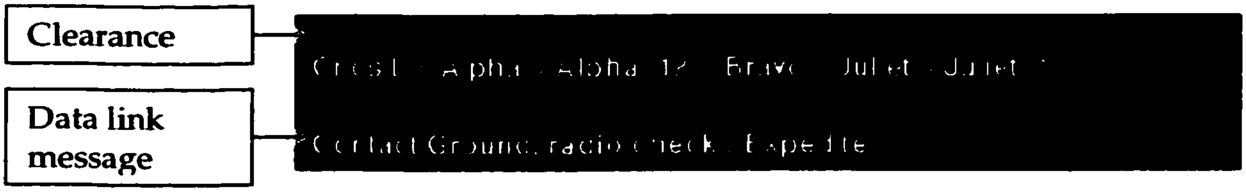

Figure 7. Expedite Text Message.

The Present Study

The main purpose of this study was to investigate whether different coding presentations of data link messages can convey a sense of urgency, which in turn should invoke a faster response to the message.

Note that it was not the purpose of this experiment to test the coding presentation effect on search performance: measurements were taken from the pilots' first dwell on the message until they initiated the appropriate action. Pilots were informed in a practice trial that a chime would announce a new message and that messages would always come up in the same place.

In this study, display coding was manipulated over five levels (plain text, expedite text, color, icon, and reverse video) in a single-factor within subjects design. Participants taxied a simulated Boeing 737 aircraft from gate to runway. While taxiing they encountered five different event types (contact ground, cleared to cross, stop, change route, and change speed).

From this information it was hoped to be able to distinguish among the five different display types for presenting time critical information.

We hypothesize that:

Hypothesis 1. Color will result in a faster response than all other displays.

Hypothesis 2. The three displays containing salience urgency coding (color, icon, and reverse video) will result in a faster response than the expedite text display.

METHOD

Participants

A total of 15 participants were tested, all of whom were general aviation (GA) pilots. There were two females and 13 males. Participants ranged in age from 25 to 56 with a mean age of 36. All 15 pilots had flown more than 330 hours (the range of hours flown was 330-4800 with a mean of 1510). None of the participants reported any color blindness; three participants had some form of eye correction, but all managed to taxi without requiring corrective lenses. Eight of the participants considered themselves moderately experienced at taxiing, one not very experienced, and six experienced. Three of the 15 participants reported using data link before.

Design

The experimental design was a single-factor within-subjects factorial design. The independent variable was Display Coding, which had five levels (Ptext, Etext, Ecolor, Eicon, and Ereverse video). Examples of each coding method can be seen in Figures 3 through 7. Each display contains the message in text. The Ptext message is just the message; the Etext message is the same as the Ptext message but contains the word expedite at the end of the message. The Ecolor display is colored red and has the word expedite at the end. The Eicon message also contains the word expedite at the end and has an icon of a triangle with an exclamation point inside it. The Ereverse video coding contained the word expedite at the end and is displayed in reverse video. Fifteen participants each completed 20 trials, five of which were no-event, leaving 15 experimental trials in which participants encountered three trials of each display coding condition.

The display coding conditions were blocked and counterbalanced between participants. For a given event, each participant experienced that event over a different set of three code conditions. This resulted in a Balanced Incomplete Block Design (BIBD) for the distribution of event types per conditions. The five different event types were Contact Tower, Cleared to Cross, Stop, Change Route, and Change Speed. The trial order of the experimental event types and coding conditions can be seen for the first participant in Appendix F.

Apparatus

Simulation hardware. The hardware used for the experiment consisted of several components. The simulated environment was created using a Silicon Graphics (SGI) Indigo 2 Extreme and projected onto a 6' high by 8' wide screen 8' from the participant's eye point using an SGI Onyx rear-projection unit. Two side windows were also present and were displayed on two 19" SGI monitors 3' from the participant's eye point. An SGI Octane was used to create the electronic moving map (EMM). In the part-task simulator, the EMM appeared as an 8" x 6" display on a 17" Sony Trinitron monitor 3.5' from the participant's eye point. The bottom two lines of the EMM contained the data link message. The participant was seated in an adjustable seat from a Chrysler Laser that was mounted on a motorized sliding track. In order to control the simulated aircraft (Boeing 737), the participant was provided a throttle, a tiller, and rudder pedals with toe brakes.

Experimenter station. The experimenter's station consisted of four 19" Silicon Graphics monitors, one displaying the simulated out-the-window (OTW) scene, one displaying a map for ATC, one showing the participant's EMM, and the other a simulation control interface. Pilots were given a headset, with a "hot mic," to communicate with the experimenter/ATC.

Eye-tracker system. To track eye movements an Applied Science Laboratories (ASL) series 5000 integrated eye/head tracking system was used. The computer, monitor, and control box for the integrated eye/head tracking unit was placed on a cart in the experimental room, while the participant wore the optics mounted on an adjustable hockey helmet.

Simulated environment. The simulated OTW scene projected on the 6' X 8' screen and the two 19" monitors was a recreation of Chicago's O'Hare airport based on 1991 CAD representations. The OTW scene perspective was modeled using pilot eye point and the acceleration, braking, and turning characteristics of a Boeing 737. The OTW scene, updated at a rate of 30Hz, included all operational runways, taxiways, taxiway and runway signs, gate markers, terminals, buildings, control tower, taxiway and runway lights, and other landmarks that would be found at Chicago's O'Hare airport.

Electronic moving map. An EMM (See Figure 8) was used in this study. The EMM used was developed under T-NASA's Terminal Area Productivity (TAP) program. The TAP program was developed to address airport delays and overcrowding. The T-NASA EMM was designed to be a secondary navigation display that aids situational awareness, navigation, orientation, and planning. Previous T-NASA studies using the EMM report increases in taxi speeds and an elimination of major navigation errors (Hooey, Foyle, Andre, Purcell & Dowell, 2000). The data link messages were displayed at the bottom of the EMM beneath the taxi clearance information. Both the taxi clearance information and the data link messages were displayed in Helvetica 24 point text, creating a .34 degree visual angle. For more information regarding the use of the map see participant instructions in Appendix D.

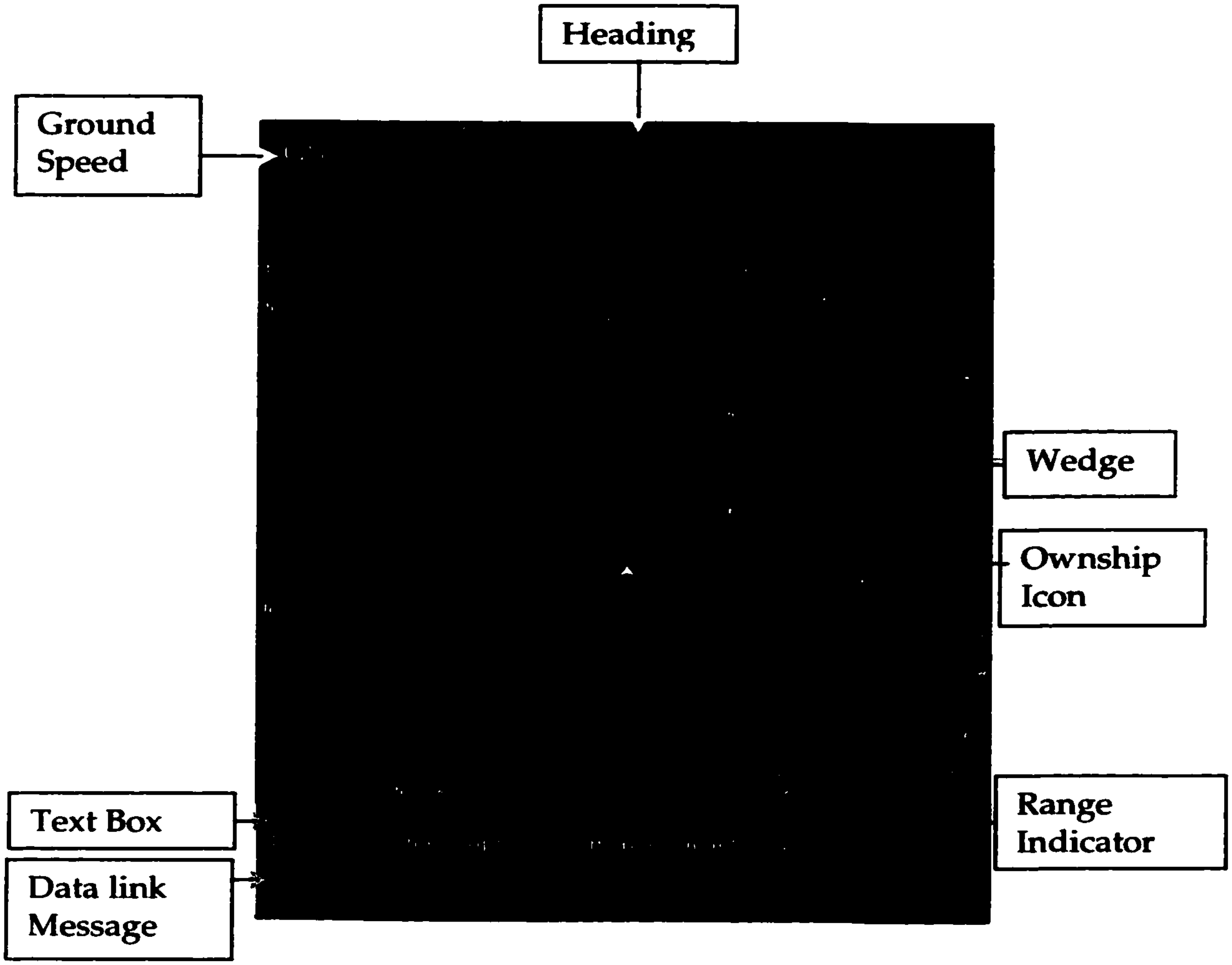

Figure 8. EMM and Data Link Display.

Procedure

Participants were met in a room separate from the part-task simulator. At this time they were given a low-risk consent form (see Appendix B) to sign and a demographics form (see Appendix C) to fill out. Participants were then given a set of general instructions explaining their tasks (Appendix D).

Next, participants were seated in the part-task simulator and the simulated environment was displayed. After answering questions regarding the simulation's features and controls, the participants were instructed on the function of the throttle, tiller, rudder pedals, and toe brakes. After answering any questions regarding the aircraft control devices, the participant was given a chance to practice taxiing around the simulation of O'Hare airport.

In the practice trial, participants used the data link display containing a contact ground message, the message was displayed in the Etext condition and a chime sounded as the message was displayed. After the message had been responded to, participants were able to complete the practice trial.

At the beginning of each trial, the participant received a data link message containing their clearance, the clearance was also read to them by ATC, the pilot confirmed by repeating the clearance and accepting the message. After responding, the pilot was cleared to taxi. Communications between ATC and the pilot during trials was limited to situations where the pilot was off route, did not comply with instructions, asked for directions or present location from ATC, or asked ATC questions regarding other aircraft. After completing all 20 trials the participants were given a survey, interviewed, debriefed, and thanked for their participation.

Dependent Variables

The following data was collected by the eye-tracker and taken from the simulation system:

Eye-Tracker. For each event, the time from the pilot's first dwell on the message until they initiate the required action was measured.

Simulation. Mean taxi time and magnitude of change data were collected from the simulation. The magnitude data collected is a composite measure of both human and system responses. Magnitude data collected included the maximum longitudinal acceleration recorded as a response to the Cleared to Cross and Speed Up events, the maximum longitudinal deceleration from the Stop and Slow Down events and the maximum nose wheel steering angle for the Change Route events.

Survey. (See Appendix D). The survey was conducted to assess the pilots' data link display design preferences for time critical messages. The survey compared the Etext, Ecolor, Eicon, and Ereverse video message coding methods for presenting time critical messages.

RESULTS

The data was analyzed by single-factor within-subjects analysis of variance

(ANOVA) for Mean taxi speed and dwell-to-response times (collapsing across the five event types). Alpha for all ANOVAs was set at 0.05.

The dwell-to-response ANOVA sought to investigate our first hypotheses, that color will result in a faster response than all other displays. A single-factor within-subjects complex comparison investigated our second research hypothesis that displays containing salience urgency coding (Eicon, Ecolor and Ereverse video) will result in faster response than the expedite text display (Etext). Pairwise and complex comparisons were performed to further investigate response time differences between the different coding conditions.

Next, the dwell-to-response times were separated out by event type and ranked in order of fastest to slowest. The magnitude of response values were then also separated out by event type and ranked in order from largest to smallest response.

Finally, subjective survey data on the display coding methods and pilot recommendations were analyzed.

Mean Taxi Speed

To test the validity of the study the first set of analyses examined mean taxi speed. It was expected that the different message coding methods would not affect mean taxi speed, as the message processing is such a small part of the overall trial that lasted several minutes.

A single-factor within-subjects ANOVA was conducted comparing total taxi time for the five different display coding conditions. This analysis was not significant $F(4,236)=.87$; $p>.05$ n.s. (see Figure 9 for a graph of the means and standard errors). This result suggests that mean taxi time did not vary under the different message coding conditions.

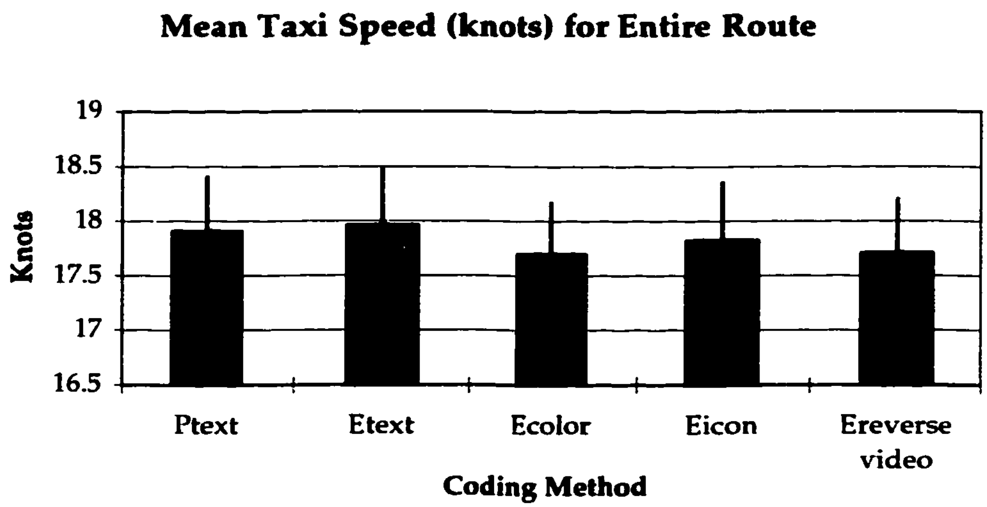

Figure 9. Mean taxi speed (knots) for entire route. Error bars indicate +1 or −1 standard error.

Message Response Time

To test our first research hypothesis that the use of color coding will result in a faster response than the other displays a single-factor within-subjects ANOVA was conducted comparing the mean response time for each of the display coding methods. Recall that response time was measured from the pilots' first dwell on the message until they initiated the required action.

The ANOVA showed no significant effect of display type on the mean response time to the messages $F(4,176)=.74$; $p>.05$ n.s. Figure 10 shows that the response times for all of the coding methods are within one standard error of each other: Ptext ($m=4.87$), Etext ($m=4.77$), Ecolor ($m=4.47$), Eicon ($m=4.29$), and Ereverse video ($m=4.68$). This result does not provide support for our first research hypothesis.

To test our second research hypothesis, that the three displays containing salience urgency coding (Ecolor, Eicon, and Ereverse video) will yield a faster response than the Etext display a single-factor within-subjects complex comparison was conducted. The complex comparison combined response times for the Ecolor, Eicon and Ereverse video conditions and compared these to the Etext condition. The complex comparison showed no significant difference between the two groups of coding methods $F(1,44)=.63$; $p>.05$ n.s. (see Figure 11 for graphs of the means and standard errors). This result does not provide support for our second research hypothesis.

A pairwise comparison was performed for Ptext and the Etext coding conditions to determine if adding the word expedite resulted in any performance gain over having just the message; the means scores were not significantly different $F(1,44)=.04$; $p>.05$ n.s. indicating no performance gain. A complex comparison was also conducted between the Ptext and the combined Saliency coding conditions (Ecolor, Eicon and Ereverse video) in order to determine if the Saliency coding conditions resulted in any performance gain over just the message, this comparison was also not significant $F(1,44)=.63$; $p>.05$ n.s. suggesting that the Saliency coding conditions did not provide any performance advantage.

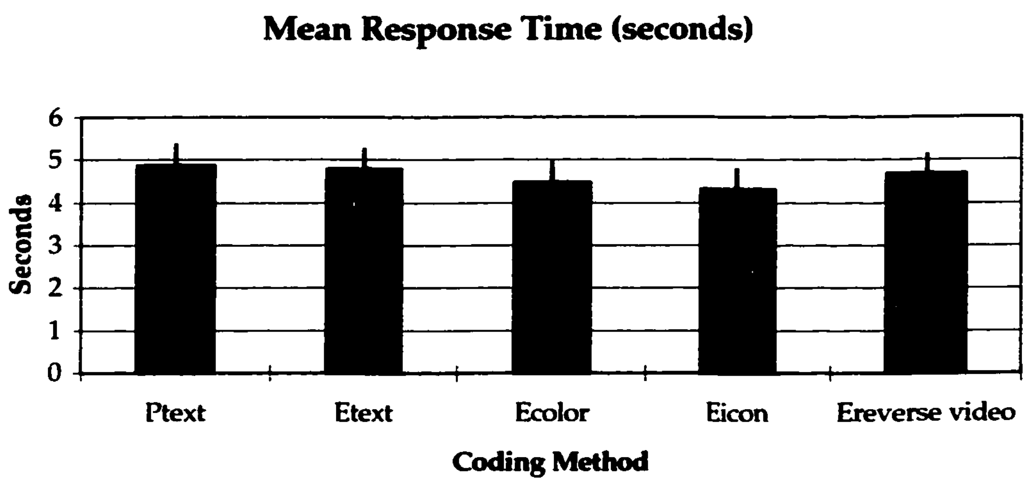

Figure 10. Mean response time (seconds). Error bars indicate +1 or –1 standard error.

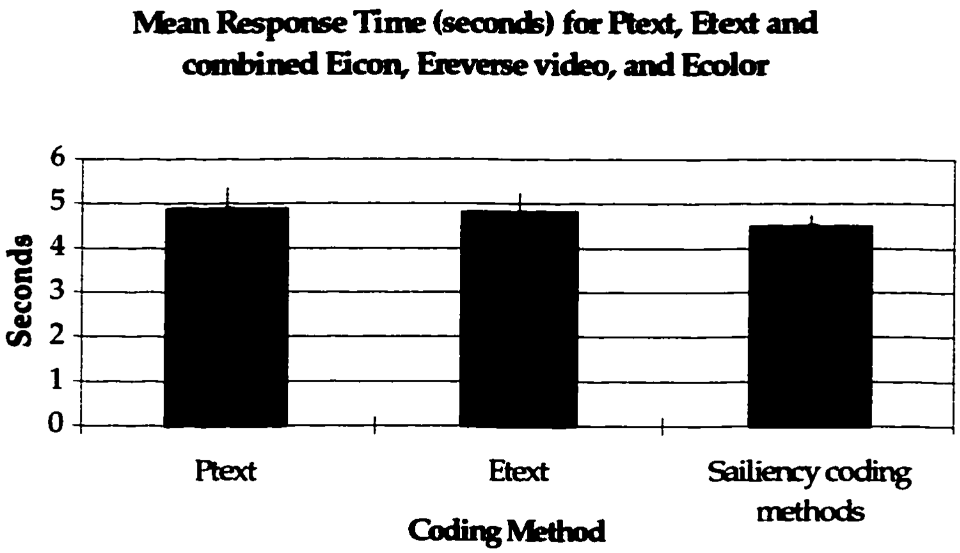

Figure 11. Mean response times for Ptext, Etext, and combined Eicon, Ereverse video, and Ecolor. Error bars indicate +1 or –1 standard error.

<u>Mean Response Time Broken Down by Event</u>

Further investigation of the mean response times indicates that different event types resulted in different ranges of mean response times (see Table 2 for means). For example, the range of response times for the event type "Contact Ground" is from 3.00 to 4.36 seconds, whereas the response time range for the event "Cleared to Cross" is 6.91 to 8.20 seconds.

In order to determine what effect the event types have on the response time, Table 3 ranks the coding method response time for each message type, with 1 being the fastest response and 5 being the slowest.

It should be noted here that the rankings should be interpreted with caution, as the differences between the means are very small. The rankings do show some support for our first research hypothesis that Color Coding will yield the fastest response, in that it has the lowest sum of the overall rankings and has the second overall mean. The Eicon display had the lowest overall mean and the second lowest sum of overall rankings. Color was ranked lowest for two of the events (Contact Ground and Stop) and third for the remaining three events (Cleared to Cross, Change Route, and Change Speed).

The collective sum of the rankings provides some support for our second research hypothesis. The sum of the rankings for Ecolor, Eicon, and Ereverse video are all lower than the sum of the Ptext and the Etext conditions, indicating that they were generally responded to faster than all other conditions. It is important to note the bi-modal nature of the Ptext and the Eicon coding conditions. For three event types (Contact Ground, Cleared to Cross, and Stop) Ptext was ranked the second fastest response time, but for the remaining two event types (Change route and Change Speed) it was ranked last with the slowest response time. Similarly, Eicon was ranked fourth fastest for the Contact Ground and the Cleared to Cross events, third for the Stop event, and first for the Change Route and Change Speed events.

Table 2

Mean Response Times (seconds) for Message Coding Method Broken Down by Event Types

		Message Coding Method				
		Ptext	**Etext**	**Ecolor**	**Eicon**	**Ereverse video**
Event	**Contact Ground**	3.51	4.36	3.00	3.82	3.61
	Cleared to Cross	7.11	8.20	7.68	7.81	6.91
	Stop	1.54	1.63	1.32	1.56	1.57
	Change Route	7.21	6.58	6.34	5.46	6.26
	Change Speed	5.21	2.90	3.39	2.51	5.04
	Overall Mean	4.92	4.73	4.35	4.23	4.68

Table 3

Mean Response Time Broken Down by Message Coding Method and Then Ranked

Ranking						
		Ptext	**Etext**	**Ecolor**	**Eicon**	**Ereverse video**
Event	**Contact Ground**	2	5	1	4	3
	Cleared to Cross	2	5	3	4	1
	Stop	2	5	1	3	4
	Change Route	5	4	3	1	2
	Change Speed	5	2	3	1	4
	Overall Mean (Ranked)	5	4	2	1	3
	Sum of Rankings	16	21	11	13	14

Note. A Ranking of 1 indicates the fastest response and 5 being the slowest response.

Magnitude of the Response

While magnitude of response was not specifically part of our research hypotheses it is of interest to know if there is any correlation between the coding conditions that were responded to the fastest and the coding conditions that were responded to with the greatest magnitude of response. To investigate if the different message coding methods affected the magnitude of the response we looked at the mean absolute acceleration change for the Cleared to Cross, Stop, and Change Speed event types, shown in Table 3. Also shown in Table 3 is the maximum steering angle for the Change Route event. Recall that the response magnitude is a composite measure of both human and system responses. The magnitude data collected refers to the maximum longitudinal acceleration recorded as a response to the Cleared to Cross and Speed Up events, the maximum longitudinal deceleration from the Stop and Slow Down events, and the maximum nose wheel steering angle for the Change Route event. Note that as there was no magnitude data for the Contact Ground event, so the design is incomplete and prevents us from performing further statistical analysis. The descriptive statistics, shown in Figure 4 (Maximum Acceleration Change) and Figure 5 (Maximum Steering Angle) indicate that all the message-coding methods magnitude of responses are within one standard error of each other.

Rankings of the magnitude of the response are shown in Table 4 with a ranking of 1 indicating the greatest magnitude of response and 5 being the smallest. Recall that the differences between the means are very small so rankings should be interpreted with caution.

Table 5 shows the magnitude of response ranked by message type. A ranking of 1 indicates the largest response and 5 indicates the smallest. Both the mean and the sum of the rankings suggest the Eicon display had the largest magnitude of response followed by Ereverse video, then Ecolor, Etext and Ptext.

Table 6 shows the sum of the rankings and the means from the event types where magnitude data was collected (Cleared to Cross, Stop, Change Speed, and Change Route) as well as the means and sum of the rankings for the response times for the same events.

Pearson correlation coefficients were calculated comparing reaction time to magnitude of response data for the coding methods mean scores and the sum of the rankings. Though the correlation's were not significant (mean scores $r(8)={}^{+}.44$ and sum of rankings $r(8)={}^{+}.72$) they do indicate a general trend for a fast response being coupled with a strong magnitude of response.

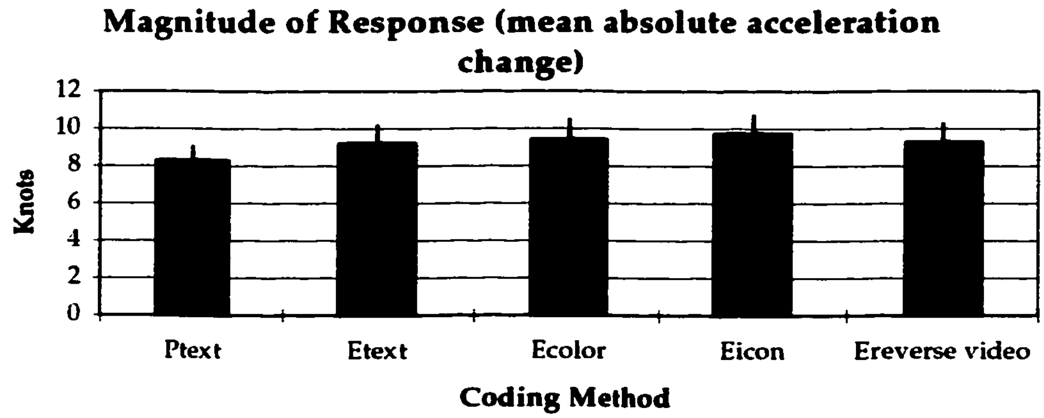

Figure 12. Magnitude of response (mean absolute acceleration change) for Cleared to Cross, Stop and Change Speed event types. Error bars indicate +1 or –1 standard error.

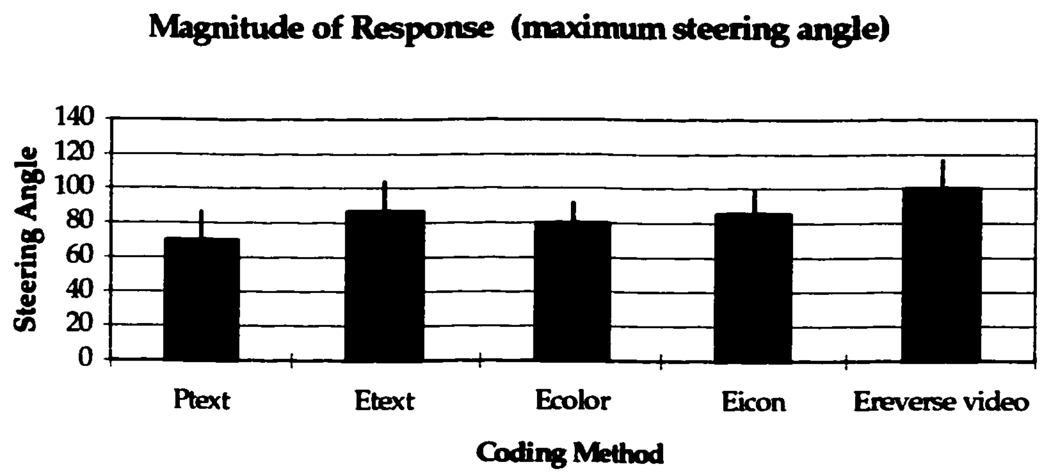

Figure 13. Magnitude of response (mean maximum steering angle) for the Change Route Event. Error bars indicate +1 or –1 standard error.

Table 4

Means for Magnitude of Response Broken Down by Event Type

		Coding Method				
		Ptext	**Etext**	**Ecolor**	**Eicon**	**Ereverse video**
Event	**Cleared to Cross**	10.63	9.54	10.70	10.88	10.87
	Stop	6.89	6.38	5.89	7.66	7.40
	Change Speed	7.22	11.59	11.52	10.61	9.52
	Change Route	69.78	86.47	79.52	85.27	99.85

Note. Magnitude of response equals maximum absolute acceleration change for Cleared to Cross, Stop, and Change Speed, and maximum steering angle for Change Route events.

Table 5

Magnitude of Response Broken Down by Event Type and then Ranked

		Coding Method				
		Ptext	**Etext**	**Ecolor**	**Eicon**	**Ereverse video**
Event	**Cleared to Cross**	4	5	3	1	2
	Stop	3	4	5	1	2
	Change Speed	5	4	2	1	3
	Change Route	5	2	4	3	1
	Mean Ranking	4.25	3.75	3.5	1.5	2
	Sum of Rankings	17	15	14	6	8

Note. Rankings, with 1 being the greatest magnitude of response and 5 being the smallest.

Table 6

Comparison of Ranking Reaction Time and Magnitude, Means and Sums

Coding Method	Mean Ranking Reaction Time	Mean Ranking Magnitude	Sum of Rankings Reaction Time	Sum of Rankings Magnitude
Ptext	3.50	4.25	14.00	17.00
Etext	4.00	3.75	16.00	15.00
Ecolor	2.50	3.50	10.00	14.00
Eicon	2.25	1.50	9.00	6.00
Ereverse video	3.67	2.00	11.00	8.00

Survey Data

Recall that the survey compared the Etext, Ecolor, Eicon, and Ereverse video message coding methods for presenting time critical messages.

Detection, reaction and interpretation. Figure 5 shows the subjective data for the participants' display coding preferences for carrying out the detection, reaction, and interpretation tasks. Eleven participants (73%) thought that the Ecolor display was easiest to detect. Thirteen participants (87%) thought that the Ecolor method of display would be the fastest to react to. Ten participants (67%) thought that the Ecolor display was "easiest" to interpret the need for urgency.

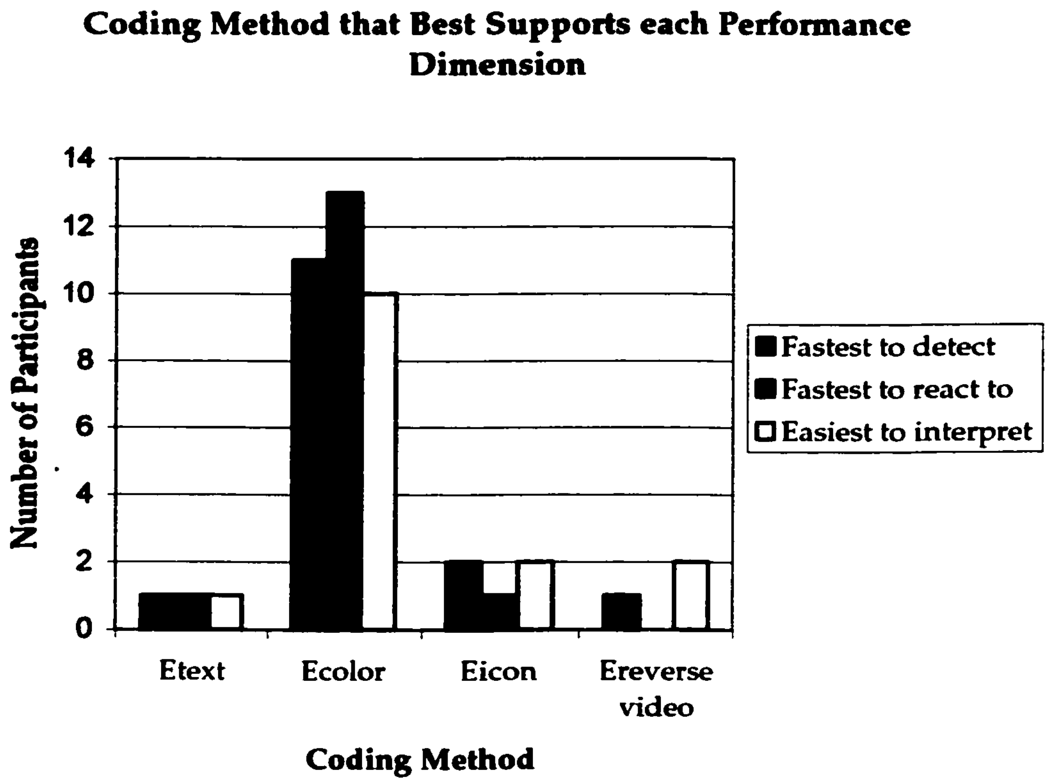

Figure 14. Coding method participants felt best supports each performance dimension.

Should any of the coding methods not be used? When asked if any of the presentations (coding methods) should not be used to display time critical information seven participants (47%) thought that the Etext display should not be used. Three people (20%) thought that the Eicon display should not be used and one person (7%) thought that the Ecolor coding should not be used. Reasons given for not using a given display are shown in Table 7.

Table 7

Participant Responses to: "Should any of the presentations (coding methods) not be used to display time critical information?"

Number of Participants	Presentations that should not be used to display time critical information	Comments
7/15	Etext should not be used	"Doesn't look different enough" "Looks similar to the taxi instructions – not eye catching"
3/11	Eicon should not be used	"Hard to refocus" "I don't care for the exclamation point/triangle at all" "Makes you think what is it?" "I interpreted the symbols as change indicators as seen in other CBT/Sim presentations"
1/15	Ecolor should not be used	"To much visual clutter"

Define or design a better display. When asked to define or design an alternative, better way to indicate urgency in a message, five participants indicated that they would use color (four participants specifically mentioned using red again) and five participants said that they would have either all or some of the screen flash. All suggestions are shown in Table 8.

Suggested changes to the current display. Table 9 shows the range of responses to "For the presentation that you preferred in our study what changes would you suggest making to it?

Table 8

Participant Responses to: "Define or design an alternative, better way to indicate urgency in a message."

Participant	**Response**
A	"Make text bigger; first draw it right under ownship so that it is closer to where you are looking"
B	"Something that will draw attention to it. Needs to be much different from what pilot has been continuously looking at"
C	"Presentation "e-color" with the word "expedite" flashing"
D	"Presentation "e-color" worked well – maybe have text blink/flash a few times to draw attention before showing steady"
E	"Red color and possible "flashing" of the urgency message"
F	"To me red is urgent it could also flash"
G	"Contact ground radio check: **Expedite** (Make the word expedite big & bold) Use serif font Use upper/lower case If it is really urgent flash the entire screen red three times"
H	"Ecolor and Ereverse video combo. White background with red letters or yellow" background with black letter. Maybe use of capital or bold letters"
I	"Like the Ecolor presentation and add Blinking"
J	"Expedite has its own color and/or flashes"
K	"Like Eicon presentation - very similar to standard computer messages"
L	"I'd use Ecolor other than red for the range that you're on. Red usually means an error or warning"
M	"A very good presentation"

N	"Verbal/audio call outs might work well"
O	"Loss of controller tonal quality in voice is a big loss useful information to this pilot" "I want to know/hear and hear read backs of other aircraft"

Table 9

Participant Responses to: "For the presentation method that you preferred in our study what changes would you suggest making to it."

Participant	Response
A	"It worked well, I can't think of any changes, I guess it would be better to put expedite on top of the message to help understanding. Usually if they tell you to expedite it means go faster. In this experiment sometimes"
B	"The red is good (add flashing)"
C	"Change message box to display ahead of track to go in field of view when transitioning from outside scan to position/track presentation"
D	"Add "Flashing" of the message"
E	"Flash the message"
F	"Larger font for rapid response" "Use serif font"
G	"Use of capital or bold letter n key words, in key elements i.e., I would see contact ground but sometimes would read radio check"
H	"To have the clearance updating as we go along"
I	"Flash expedite"
J	"None the red prompt was easily the best for me"

DISCUSSION

Dwell to Response

The main purposes of this study was to investigate if urgency could be coded into a data link (written) message and to determine which urgency coding facilitates the fastest correct response. The results suggest that the different message coding methods did not significantly affect overall response time to the messages. While a post-hoc rank analysis did show an overall benefit for the color coding condition relative to the other coding methods used (Ptext, Etext, Eicon and Ereverse video) this was only for two event types (Contact Ground and Stop). However, the rankings do suggest that the three coding conditions that contained a visual form of urgency coding (Ecolor, Eicon and Ereverse video) yielded consistently faster ranked responses than the text-based codes (Ptext and the Etext).

It is interesting to note that previous studies investigating ways to aurally alert pilots of new messages by van Gent (1995) and Rehmann (1996) did not find performance differences, which may suggest that in the context of data link communications it is difficult to measure performance changes caused by different methods of alerting pilots. Despite the lack of significant effects in the performance data, it is important to note that the pilots strongly indicated that coding the urgency level into data link messages is a critical issue. For example, one pilot stated that "the loss of controller tonal quality in voice is a big loss [of] useful information."

A number of factors in this study made it difficult to accurately tell if our coding schemes had any performance implications. The first of these factors is the slight confound that the pilots were not highly or multi-tasked during the experiment. This meant that when a message was received the pilots reacted to it quickly, as apart from taxiing they were not required to perform any other tasks. The second factor is that the messages were short (less than one line); the entire message was coded (not just a part of the message) and was not part of a larger, multi-message display where a pop-out effect similar to that suggested by Martin and Wickens (1995) would be advantageous.

In reviewing the ranking data it is also of interest to note that some coding methods produced variable response times; this may suggest that different events may be best suited by different coding methods. The results from this study tend to indicate that messages such as Contact Ground and Stop may be best presented either by color or plain text, whereas an icon may best present Change Route and Change Speed. Some of the variation in response times to the different event types could be attributed to message expectancy and message content. When pilots are taxiing an aircraft they adopt behaviors that meet goals such as fuel consumption efficiency and safety. For example, pilots will often try not to come to a complete stop or avoid braking abruptly so that they can minimize their fuel consumption and so that air crew and passengers are not put at risk. These behaviors result from the pilots attempting to anticipate situations which may mean that they react to situations prior to messages arriving or read the message and then act in a way that will not increase fuel consumption or put air crew and passengers at risk. It was intended that the simulation of other aircraft and the events used in this study would provide a realistic context. However, seeing another plane crossing a runway ahead on the EMM display may result in the pilot responding in anticipation in a timely fashion but with a smaller degree of magnitude of response. Message expectancy may have resulted in pilots reacting with different levels of urgency due to how expected each message was in the context of the trial they were in. For example, a Stop message prior to a runway may be seen as more urgent than a Contact Ground message received at the same time. It is also likely that some messages invoke a greater sense of urgency than others do. For example, in our study a message to Stop was responded to faster than any other event. We suggest that out of all the event types used in our study this is the event that invokes that greatest sense of urgency.

An interesting observation from the study was that it was apparent that some pilots interpreted the word "expedite" slightly differently in the written form than when spoken by an air traffic controller. In the current voice environment the word expedite typically means "perform the task faster regardless of ground speed"; in this study some pilots saw the written word expedite as an instruction to just increase their ground speed.

Magnitude of Response

Rankings of the change in magnitude data for the message types Cleared to Cross, Stop, Change Speed (maximum acceleration change) and Change Route (maximum steering angle) suggest some degree of correlation between a fast response and a high magnitude of response. The ranked order for dwell-to-response times was (from fastest to slowest) Ereverse video, Eicon, Ecolor, Ptext, Etext; the ranked order of change-of-magnitude was Eicon, Ereverse video, Ecolor, Etext, Ptext (from largest magnitude to smallest).

It is expected that taxiing behaviors that lead pilots to respond in ways that meet goals for fuel consumption efficiency and safety as mentioned previously would also affect the magnitude with which pilots responded to messages. These behaviors are the result of the pilot attempting to anticipate situations so that they can act early with a smaller degree of magnitude.

Survey Data

When asked which coding method was easiest to detect, fastest to react to, and easiest to interpret, participants preferred the Ecolor coding display. When asked more specifically if any of the presentations should not be used one participant did raise questions about the use of color, stating too much visual clutter as the problem. However when asked to define or design a better display, five participants indicated that color should be used, with four of the five mentioning use of red. Seven participants thought that the Etext display should not be used, as it did not stand out enough and three participants felt that the Eicon coding display should not be used as they had difficulty interpreting it.

Participants made the following design change recommendations for urgent messages: that the screen should flash, the use of clearer text (a serif type was mentioned), use of capital letters and bolding and the use of color as mentioned above. Legibility of the display was also an issued raised by pilots with some finding our display hard to read.

The survey data does suggest a preference for the use of color. Participants' preference for the red display (Ecolor) over the other displays for presenting time critical messages did not correspond to a better performance when messages were colored in this method. This "performance preference disassociation" is similar to that described by Andre & Wickens (1995) whereby a display coding feature, such as color, is rated highly as a performance factor due to its subjective appeal. In this study many of the participants were particularly critical of the icon display, yet the performance difference between the icon and the color-coding methods was minimal. This result suggests the need for caution in using subjective preference data without collecting corresponding performance data.

Implications of this Study

Need. The change from any voice communication system to a text based system raises questions about how to best display the information. The change in aviation from the radio-telephone communication system to data link messaging presents the challenge of how to best display the urgency level of a message that would previously have been transmitted via speed of speech and tonal intonation. The pilots in this study clearly confirmed the importance of developing a method of communicating urgency in data link messaging systems.

Data. This study presented the first test of coding message urgency into data link messages. While not statistically significant the data does show a small trend for the benefit of using some form of salience coding "color, icon or reverse video" for conveying urgency, as opposed to a simple text message or the message preceded by the word "expedite."

Preference. While participants preferred the color coding presentation, this preference did not translate to a faster response time. This result could be explained in two ways. First, it could be that there is a performance difference in reaction time to the different coding methods but that the measurement techniques in our study were not sensitive enough to capture the performance change. Second, it may be that there is performance preference disassociation similar to that mentioned in Andre and Wickens (1995) in that the pilots' preference for the color display leads them to consider it as better. We believe that both explanations about this disassociation are true and that the main influence should be determined in future studies. This position is taken for the following reasons. First, as was mentioned previously there were a number of factors that would make it hard to accurately measure any real differences, (e.g., short, simple messages in a low-task environment), providing support for our first explanation. Second, the trend for salience coding to show some performance advantage suggests that our study did find some small but consistent performance differences, also providing support for our first explanation. However, there was no consistent performance difference between the saliency coding methods, or more specifically between the icon and the color coding methods. This suggests that the participants responded equally well to these two different coding methods yet participants reported both that they responded faster to the color coding method and that some of them were confused as to what the icon represented, providing support for our second explanation.

Future. Further research needs to be conducted to determine if improvements in response times and behaviors can be shortened in environments where pilots are carrying out greater task loads with messages of greater complexity. It may be that coding urgency does not work with simple messages under low workload.

There is also a need to determine optimal alternative displays. For example, if an icon display is to be used it may be that a better icon could be found. Similarly, if color is used it may be that a better color can be determined. For example, given that the coding method is to indicate expediting an action, a color such as green, which indicates go, may be used. However, using green may result in difficulties for messages such as stop. In determining the best color it is important to keep in mind Degani's (1992) observation that in aviation red is associated with danger, green with normal and amber with caution. In addition to determining the most appropriate color for the message, research needs to be conducted into the best font type and size and background color as some participants in our study expressed some difficulty in reading our display. In providing recommendations for the typography of printed flight-deck documentation Degani (1992) recommends against the use of white text on black for most documentation as black on white can seen at greater distances and from a larger angle from line-of-site. Degani (1992) proposes that white text on a black background can be a good method to emphasize information. Degani (1992) has the following recommendations for instances where white text on a black background is used: text should be kept to a minimum, be of relatively large font type and be sans-serif. It should be noted here that Degani's recommendations were primarily meant for printed material and therefore care should be taken in interpreting their utility for an emissive display such as a CRT.

In terms of an optimal coding scheme it may be that a combination of the techniques used in this study or other techniques is better. From this study the following appear to be plausible design methods for communication of urgency:

- Flashing -- perhaps the screen could flash three times to indicate a new message
- Color
- The use of capital letters and bolding
- A multiple line display whereby one line (the last line) is dedicated to urgent messages
- An icon that is universally representative of urgency
- Coding just the word expedite instead of the entire message

An example of some of these coding methods can be seen in Figure 15.

Figure 15. Multi-part data link message with the text "EXPEDITE" coded red.

Future research should also focus on message detection, as it is important that any coding method selected should aid pre-attentive cueing as well as convey the required level of urgency.

A future study should also be conducted that focuses on scheduling choices as well as response initiation time. We suggest that scheduling choices may give an alternative method of determining how urgent a message is perceived to be.

While the results in this study were not definitive they do highlight the need and suggest that it may be possible to code urgency into data link messages. The survey data also suggests that pilots feel the need for coding a distinction between messages of different urgency.

Conclusion

This study provided a preliminary investigation of the potential to code message criticality into a pilot's data link display. The data from this study, whilst not conclusive, does suggest that it may be possible to invoke a faster response to messages by using one of the following coding methods: coloring the message red, using an icon, or by displaying the message in reverse video. This study highlights the need for further research to find an effective way to distinguish between urgent and non-urgent critical messages for text-based communication systems, such as data link in aviation.

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Appendix A. Signed Approval Form

San José State
UNIVERSITY

Office of the Academic Vice President

Associate Vice President Graduate Studies and Research

One Washington Square
San José, CA 95192-0025
Voice: 408-924-2480
Fax: 408-924-2477
E-mail: gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

TO: Joanne Lins
1315 MLK JR Way, Apt., #5
Berkeley, CA 94709

FROM: Nabil Ibrahim, N. Ibrahim
AVP, Graduate Studies & Research

DATE: May 8, 2000

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"How Should Message Criticality be Displayed on a Data Link Screen"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

Appendix B. Consent Form

Agreement to Participate in Research at San Jose State University

Responsible Investigator(s): **Joanne Lins (Student), and**
Dr A Andre (Professor)

I have been invited to participate in research on how to display critical information on a data link display.

The possible benefits I might gain from my participation include learning more about data link displays. The possible risk is minimal eye strain equivalent to what might occur from 2 hours work on a computer. I understand that my participation in the experiment is voluntary.

If I decide to participate, I will be asked to taxi an aircraft, while wearing an eyetracking helmet, in a high fidelity part task simulator for 16 trails. The trials will be broken down into 4 blocks of 4 trials, each block should last no more than 25 minutes. Between each block of trials a 10 minute break will be given; the entire procedure should take 2 hours.

Data gathered from this study will be stored on a computer disk and will be held in a locked file, which no one but the experimenter will be able to access. In case the results from this study are published, any information that is obtained from me in connection with this study and that can be identified with me will remain confidential.

My decision to participate or not participate will not in any way prejudice my future relations with San Jose State University. If I decide to participate, I am free to with draw my consent and to discontinue my participation at any time without penalty.

If I have any questions, I may ask them prior to the start of the experiment. If I have any questions after the experiment, I may contact Dr. Andre at 408-342-9050 or Joanne Lins at 510-528-2021. If I have any complaints about the procedure, I may contact Dr. Kevin Jordan, Psychology Department Chair (Acting) at 408-924-5600 (DMH 157). For questions about research participants' rights, or in the event of research-related injury, I may contact Dr. Nabil Ibrahim, Associate Vice President for Graduate Studies and Research, at 408-924-2480.

I am making a decision whether or not to participate. My signature indicates that I have decided to participate having read the information provided above. I have received a copy of this consent form for my records.

The signature of a researcher on this document indicates agreement to include the below named participant in the research and attestation that the participant has been fully informed of his or her rights.

Signature Date

Investigators Signature Date

Appendix C. Demographic Form

Demographic Form

Name ______________________________ Subject # _____

Age _________

Gender ☐ male ☐ female

Do you have a form of color blindness or color vision deficiency? ☐ yes ☐ no

Do you wear glasses or contact lenses? ☐ yes ☐ no

What type of aircraft do you currently fly (specific make, model version)

____

Approximately how many hours have you flown _____________

How experienced are you at taxiing an aircraft:

☐ not very experienced ☐ moderately experienced ☐ very experienced

How often have you used a data link display

☐ never used one before ☐ moderately experienced using one ☐ very experienced

Appendix D. General Instructions

General Instructions

Welcome, and thank you for participating in this study. Your efforts will be instrumental in helping us assess the usefulness of our Electronic Moving Map (EMM) display, an electronic navigation aid to help pilots efficiently and safely taxi the airport surface.

Background to the study

The EMM was developed as part of the Taxiway Navigation And Situation Awareness (T-NASA) display suite under the auspices of Terminal Area Productivity (TAP), a major NASA program whose goal is to safely increase the traffic-handling capacity of existing airports. TAP encompasses a wide range of operational and technological initiatives, including reducing aircraft separation, creating a more efficient air traffic management system in the terminal area, and improving the efficiency of low visibility landing and surface operations.

To test the utility of the display we created a part-task simulation facility of Chicago-O'Hare airport, rear projected onto a wide screen. While inside the simulation environment, we ask you to assume the role of the captain of a commercial airliner with passengers on board. On each of the twenty 'trials,' we ask that you guide your aircraft from just outside a gate to a runway departure point as quickly, accurately, and safely as possible.

Clearances:

Your taxi clearance, and other instructions, will be displayed at the bottom of the EMM display. At the beginning of each trial, NASA Ground Control (your experimenter) will review your initial clearance over the radio. After that, you may get further instructions during your trial. These messages will always be preceded by a chime. Some of the messages may ask you to expedite the required action; in these instances please carry out the requested action as soon as possible.

More details on procedure:

- Never guess the direction of a turn. Always attempt to follow the cleared route as closely as possible. If you get lost, check with Ground Control via the microphone on your headset.
- There are a number of inconsistencies between our departure scenarios and the real world. The primary differences are the general absence of other runway traffic, and the associated absence of background ATC communications. However, to try and minimize the 'video game' quality of the experience, we have programmed occasional, unexpected incursions by other aircraft. Please be on the alert for these incursions at all times. If you collide with the other aircraft, the screen will flash two or three times to indicate the collision. If this happens, the trial will terminate.
- Incursions are traffic that are within an designated area and traveling in a certain direction so that they might lead to an accident. These incursions may

or may not happen though while you are participating in the experiment.

Limitations of the Simulation Facility

The vehicle model approximates the handling characteristics of a Boeing 737. However, you will be the only crewmember and you will quickly notice the absence of aircraft motion. We beg you indulgence for these limitations! Some of the simulator limitations are by design, while others are constraints of the simulation environment. Once again, we greatly appreciate you participation in this simulation.

Map Feature Instructions

There are several components that comprise the Electronic Moving Map (EMM) display. In the following section the main features will be briefly discussed, a chance to become more familiar with them will be given during a practice period. This is what the EMM looks like:

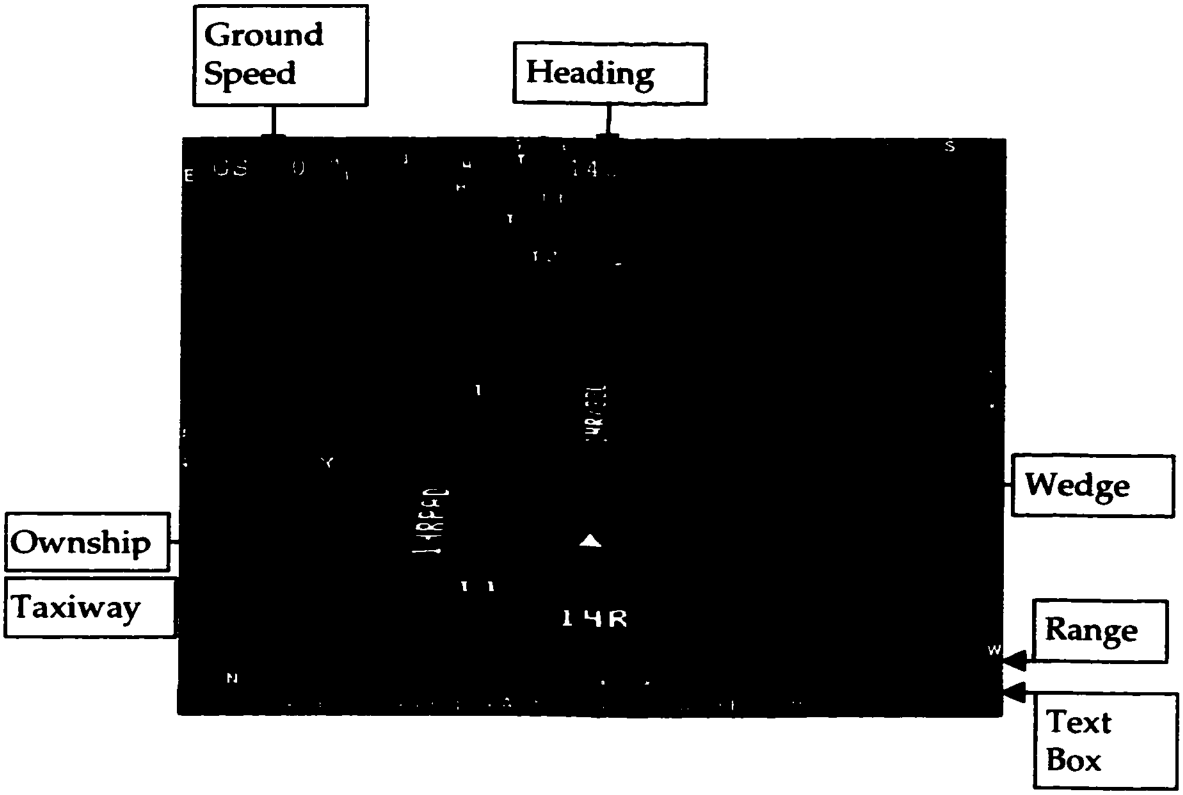

Figure 1. EMM showing heading, ownship icon, wedge, range level indicator, text box, route guidance, ground speed, taxiway labels.

Track-up orientation: The EMM is a track-up rotating map. In other words it is not fixed in a North-up orientation, but instead it rotates in sync with you as you navigate the airport surface. It should be noted here though that the overview modes are fixed in a North-up orientation.

- **Route Guidance**: The cleared taxi route is represented on the EMM as a thick magenta line. The graphical representation of the cleared route matches exactly to the data link route clearance. (See Figure 1).
- **Compass Bars / Heading**: The EMM provides two heading cues. The first cue is the heading bars that frame the EMM. These heading bars are colored gray, labeled N, S, E, & W, and rotate as a result of the map being track-up. The purpose of these heading bars is to orient you when clearances are given using cardinal headings (e.g. "Turn south on Tango"). There is also a digital compass heading readout that is permanently displayed on the top center of the map (See Figure 1).
- **Ownship (OS) Icon**: The OS icon is a white triangle with the apex representing the nose of the aircraft. This icon will always be centered and a third from the bottom of the screen (See Figure 1).
- **Wedge of Importance**: The wedge of importance represents the area of interest in front of the aircraft and extends 1,250 feet. (See Figure 1).
- **Range Indicator**: In the lower right hand corner of the graphical portion of the EMM display is a range level indicator. The color red (See Figure 1)

denotes the zoom level that is currently being used. There are 4 different zoom levels; the zoom level you use is also left to your discretion (See Figure 1).

- **Text box**: The route clearance and other information from the Air Traffic Controller is presented in the text box that comprises the bottom 1" of the display. **Note**: when a new message is displayed a chime will sound. This box is divided into 2 rows. The top row contains the textural read out of the taxi route clearance given to you by ATC. For those taxi clearances that are too long to show on the entire EMM screen a thumb wheel located on the throttle lever end will scroll the text for you so you can see your entire route (see Figure 1).
- **Ground speed**: The ground speed of your aircraft is displayed in a small box in the upper left-hand corner of the map display (see Figure 1).
- **Taxiway labels**: Taxiway labels are strategically placed on the map for optimal use while keeping clutter to a minimum. You will notice that as you change zoom levels the number of taxiway labels change. In the overview mode there are only labels for major taxiways displayed, and the inset has no labels. These labels are also presented in a track-up mode so they rotate to stay up right as you navigate the airport surface. (see Figure 1).

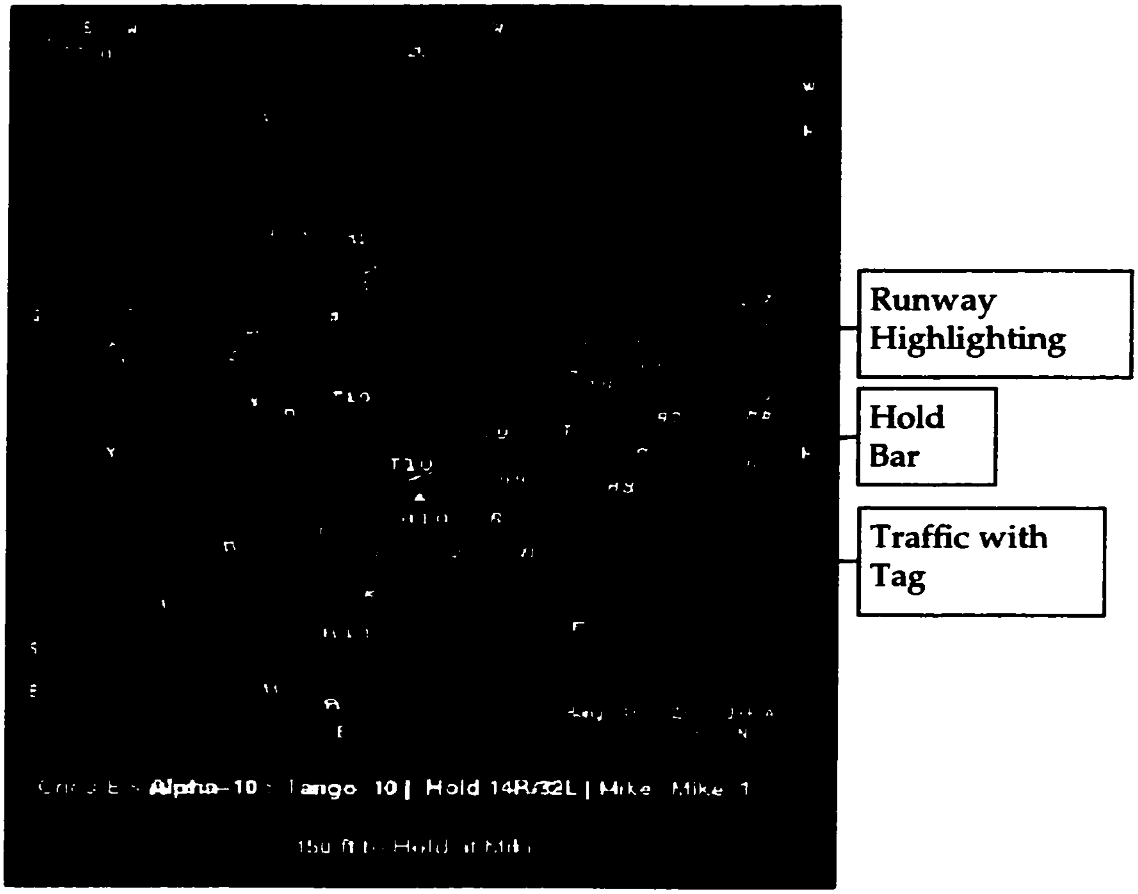

Figure 2. EMM showing runway lighting, hold bar and traffic with a tag.

Hold Bars: These are yellow bars that appear in front of an aircraft, either the OS icon or traffic icon, that is NOT cleared to cross through an intersection where an incursion is predicted. If the yellow hold bar is in front of the OS icon you are to hold short and let the traffic pass through the intersection. The magenta route guidance will turn yellow beyond the hold bar. Once a hold bar is removed the magenta route will return and you are cleared to cross through that intersection (see Figure 2).

- **Traffic**: White moving and stationary aircraft icons represent traffic and are updated in real time.
- During a **possible incursion** (within 1250') the piece of traffic in question will turn yellow (see Figure 2).
- During an **impending incursion** (within 300' or 12 seconds) the incurring piece of traffic's icon will turn red and begin to flash.
- **Traffic Tags**: The traffic tags display call sign and aircraft type, for example, DAL109/B737 (See Figure 1). These tags will be visible only when an aircraft is within your 1250' wedge of importance.
- **Runway Highlighting:** A runway that is currently occupied (whether the aircraft is landing, taking off, or crossing) will be highlighted in red bars.

EMM Usage Instructions

The Electronic Moving Map (EMM) display has been carefully design to aid eyes-out taxi. There are several features that have been purposefully built into the display to assist you in taxiing while keeping eyes-in time to a minimum. The following is a brief set of instructions that explain how the EMM should be used during taxi.

The EMM is designed to be a secondary navigational aid, **NOT** a primary or centerline tracking display. To keep you from using it as a primary display or tool for tracking the centerline of the taxiway we built in various aspects. First, we used a thick magenta band, the width of the taxiway, to show the cleared route instead of highlighting the taxiway's centerline. Second, the ownship icon is a triangle that is slightly larger than the taxiway so that it can be used to assess your general position on the taxiway (am I on taxiway Alpha?), but not the specific position of the aircraft's wheels. Third, we did not include turn vectors or predictors to aid turning.

The EMM is also designed to allow information to be gleaned from quick glances at the map. The EMM is a rotating map, therefore eliminating the need for mental rotation because what is displayed on the upper portion of the display is always what is in front of you. The wedge also affords this because it helps you find the OS icon, gives you the general heading of your aircraft, and area of importance 1,250' in front of the aircraft. By implementing these features, instead of fine detail control features, the map is designed to aid you in navigating the airport eyes-out instead of tracking the centerline and navigating eyes-in.

We feel that taxiing is an eyes-out process and we incorporated that philosophy into its design, as noted above. The map is there for you to verify heading, position on the airport surface, position relative to the cleared taxi route, the cleared route itself, ground speed, traffic movement and identification, and hold bars. It is not there to aid you in turning the aircraft, tracking the centerline, or to replace the out-the-window view. This display was not designed with the intent of making it a primary navigation aid, instead it should be used as a secondary navigation (rather than control) aid which can be incorporated into your scan pattern. It assists you in eyes-out taxi by providing information that is otherwise lost or degraded due to poor visibility. Please keep this in mind while using the EMM today and let the experimenter know when you are ready to begin.

Appendix E. Comparison Survey

Comparison Survey

This survey refers to four different ways of presenting data link messages that you encountered in your trials. The four different ways are depicted in the attached set of pictures; please refer to the pictures whenever necessary while completing this survey.

1. Please circle the presentation method that bests supports each performance dimension listed in the table below:

Performance Dimension	**Presentation Method**			
Fastest to detect	A	B	C	D
Fastest to react to	A	B	C	D
Easiest to interpret that a message requires an urgent/expedited response	A	B	C	D

2. Please rank the presentation methods in order of conveyed urgency, from 1-4, with 1 representing the best and 4 the worst.

   A_____

   B_____

   C_____

   D_____

3. Should any of these methods *not* be used for a time-critical message? If you answer yes, please list which ones should not be used and state why.

4. Please define or design an alternative, better way to indicate urgency in a message.

5. For the presentation method that you preferred in our study what changes would you suggest making to it.

-
-
-
-
-

6. Please list any other comments/suggestions regarding the different ways of presenting the data

Appendix F. Trial Order for Participant One

Table 1

Trial Order for the Participant One

Trial	Event	Coding Condition
Practice Trial	Practice trial	
1	Contact ground	Ptext
2	Cleared to cross	Ptext
3	No event	
4	Stop	Ptext
5	Slow down	Ecolor
6	Change route	Ecolor
7	Contact ground	Ecolor
8	Cleared to cross	Eicon
9	No event	
10	Stop	Eicon
11	No event	
12	Change route	Eicon
13	Slow down	Etext
14	Change route	Etext
15	No event	
16	Speed up	Etext
17	Contact ground	Ereverse video
18	Stop	Ereverse video
19	No event	
20	Cleared to cross	Ereverse video